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ATTITUDE CONTROL: A BIBLIOGRAPHY

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ABSTRACT

This report is a survey of academic literature on the attitude control of satellites and space vehicles. Only material published in English between the years 1958 and 1962 is included.

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INTRODUCTION

Definition

The attitude of a satellite or space vehicle is the orientation of its principal axis with regard to some frame of reference—in practice, the earth or a fixed star.

Control of satellite and space vehicle attitude is necessary for a number of reasons. If data is to be gathered from the earth, moon, sun or any other celestial body, the instruments for gathering such data must be oriented towards these bodies. If the data is then to be telemetered to earth by means of a directional antenna, to conserve power, the antennas must be likewise oriented in an earthward direction. Similiarly, if the power source for the vehicle is solar energy, the energy collecting devices must be oriented towards the sun.

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I. Sources of disturbance

A. General studies of disturbing torques.

Sources of attitude errors are discussed in a number of places in the literature. De Bra (29) investigates the stability of a gravity-oriented satellite in terms of its orbit. Analytical methods for studying disturbing torques are presented by Buglia and Young (113) and by Sklar (130). Michelson (91) discusses the coupling effects of rotary vibration modes. The observed torques acting on Explorer XI are investigated by Naumann (950).

B. Specific sources of disturbance

Ives (65), McIlvain (87), and Dahl, Aldrich and Herman (25) discuss the disturbing effects of solar radiation. Meteoritic disturbances are discussed by White (149); the coupling effects of the gravity gradient are described by Michelson (91); the interaction of the magnetosphere with satellite surface electricity is examined by Singer (127). Methods for computing the effect of molecular impingement are presented by Sentman (126).

II. Types of attitude control

Any attitude control system must perform the following functions: determine a definite frame of reference; sense any departure from this frame of reference; correct the attitude errors so detected. Basically, there are four types of attitude control:

A. Spin stabilization: the entire vehicle is spun about its principal axis of greatest inertia, becoming in effect its own gyroscope.

B. Internal momentum exchange: the momentum of parts within the vehicle is used, rather than movement of the vehicle as a whole, to stabilize attitude.

C. Mass ejection: the basic principles of rocket propulsion are applied in the form of reaction jets.

D. Environmental interaction: the very external sources which produced disturbances are used to produce the required corrective torques.

III. Attitude sensing

Whitford (155), Williams (156) Moore and Thomason (93) describe attitude sensing techniques. Infrared horizon scanners are described by Roberson (111), Hatcher and Germann (57) and Kendall and Stalcup (72). McMorrow, Brownlee, Dadradrian and Schwartz (89) examine the use of a precision star tracker as an attitude sensor; Salyendra and Bradford (118) present an attitude sensing system using a pair of star trackers together with a horizon scanner. The application of radar to attitude sensing is investigated by Reich (106). Other types of sensors which have potential use in attitude control are solar sensors, described by Roberson(110).

IV. Spin Stabilization

A. As sole method of control.

Singer (128) and Reiter and Thompson (107) discuss the spin stabilization of passive satellites. The amount of spin required to stabilize a satellite with attitude unstable from gravity torque is studied by Thompson (139); a system for stabilizing the spin axis of a spinning body under the influence of load torque impulses is presented by Freed (42,43). Haeusserman (54) describes the creation of torques for attitude control by means of either translation or rotational acceleration. The spin stabilization of synchronous communication satellites is examined by Kovit (78) and by Williams (156). Garber (48) obtains solutions for a spinning body which an arbitrary mass disbributicn. In a system described by Klass (75), the inherent gyroscopic properties of an earth-oriented satellite are used to achieve a semi-passive stabilization.

B. Together with other control methods.

Spin stabilization by itself may not be sufficient for attitude control. Grasshoff (52) describes the generation of a magnetic torque to assist in the attitude control of a spin stabilized satellite; Grubin (53) and Garner and Reid (49) describe the use of reaction jets to implement spin stabilization.

V. Internal Momentum Exchange

A. Reaction Wheels

1. As sole method of control.

Abzug (1) and Stuart (137) describe the use of reaction wheels (also termed inertia wheels or flywheels) to stabilize satellite attitude. Design criteria for reaction wheels are discussed by White and Hansen (150,151); equations of motion for the angular displacement of an earth-oriented satellite are derived by Ives (66). Vaeth (144) presents the results of analog computer studies of reaction attitude control. Related information is given by Groelich and Patapoff (46) in their report on a laboratory model of a single axis attitude control system using reaction wheels. McRuer and Stapleford (90) determine the power and energy requirements for a fixed axis reaction wheel system; momentum reservoir capacity for such a system is determined by Mortensen (94). Cannon (16,17,18) discusses the response relations and gyroscopic coupling of reaction wheel systems together with other control methods. To avoid the gyroscopic cross coupling inherent in reaction wheels, reaction spheres have been proposed; a system using reaction spheres for attitude control is discussed by Orinsby and Smith (100).

2. Together with other control methods

Reaction wheels may be used in conjuction with others attitude control techniques. Ergin, Norum and Winde-Knecht (39), Debra and Cannon (30), Peters, Kovacevich and Graham (103), and Alexander (4) all describe systems in which they are used together with reaction jets. Systems in which they are used with magnetic torquing are described by Eide (36) Burrow (14), and Adams and Brissenden (2).

B. Gyroscopes

Gyroscopes are another form of internal momentum exchange device. Draper, Denhard and Trageser (34) survey of the state-of-the-art of gyroscope development for attitude control. Specific systems employing gyroscopes are described by Godet (51), by Kennedy (73), and by De Lisle, Ogletree and Hildebrant (33).

VI. Mass Ejection Systems

A. Reaction jets as sole method of control.

Schmeldin (123) describes gas systems for reaction jets are also discussed by Lee (80), by Vaeth (154), by Garner and Reid (49), and by Gaylord and Keller (50). Dahl, Aldrich and Herman (25) study limit cycles in reaction jet attitude control system subject to external torques; Hultquist (64) computes the angular impulse imparted to a jet-controlled satellite; Lieberman (83) presents a mathematical model of a bang-bang-reaction-jet system. The use of self-pressurizing propellants is discussed by Couch, Hoffman, Nyberg and States (24); an approximation technique for measuring the dissipation time of nitrogen gas ejected for attitude control is developed by Brenton and Cheselske (9).

Zoeckler(162) describes the Mercury capsule reaction jet control system, which uses 90 percent hydrogen peroxide as its propellant.

B. Types of reaction jets

1. Hot-Gas

Alexander (3), Brown (10), Pemberton (102) and Wai Choo (147,148) describes the use of hot-gas reaction jet systems; Traynelis and Ryan (141) discusses the factors to be considered in choosing such systems.

2. Cold-Gas

Cold-gas reaction-jet systems are described by Nicklas and Vivian (96); the testing of such systems is described by Day and Hastings (27). Related to these gas-jet systems is the system described by Tinling (140), which uses water vapor.

C. Together with other control methods.

Several writers have discussed the actual or possible combination of reaction jets with reaction wheels. Among these are Alexander (4), Gaylord (47), De Bra and Cannon (30), Ergin, Norum and Widdeknecht (39), and Peters, Kovacevich and Graham (103).

D. Other mass ejection methods

(1)

Solid propellants

Sobey and Peterson (130,132) describe the Vectrol System, in which four small individually rotatable solid rockets are used to control the attitude of a solid propellant vehicles. Roach and Seymour (109) describe a gimballed spherical solid propellant vernier rocket for attitude control.

(2)

Vector Control

Vector control methods are discussed by Hubbard (63). In this paper, special attention is given to secondary injection, a technique in which a fluid is introduced into the exhaust cone of a rocket engine to shift the direction of the main jet, deflecting its effective thrust to control vehicle attitude.

(3)

Advanced propellants

Several methods of advanced propulsion have been proposed for attitude control. Maes (85) compares the potential effectiveness of a pulsed plasma accelerator with arc jets and ion engines; Olds (97) compares the weight, power, thrust and duty cycle requirements for cesium and mercury ion propulsion systems.

VII. Environmental Interaction

A. Use of terrestial magnetic field

(1) As only method of control

The earth's magnetic field has been used for controlling the attitude of several satellites. De Bolt (28) describes a technique of lining up one axis of a satellite or space vehicle with the earth's magnetic field. Avrech (5), McIlvain (88), Wilson (157), and White, Shigemoto and Bourquin (153) all describe the use of torque developed by the interaction of this field with a magnetic field within the vehicle. Kamm (69) describes the use of a specific device, the Magnatorquer; Hecht and Manger (58) describe the magnetic attitude control of the Tiros satellite.

1. Together with other control methods

   Magnetic torquing may be used in conjuction with other attitude control methods. Buckingham (12) and Burrow (14) both describe the use of reaction wheels for storing the momentum produced by magnetic torquing.

B. Use of other environmental conditions

   Other aspects of the space environment can also be used for attitude control.

   1. Aerodynamic forces

      Aerodynamic attitude stabilization—discussed by Davison (26), by Juelich (68), by Schrello (124) and by Harris and Johnson (56)—can be used with passive near earth satellites.

   2. Solar radiation

      Hibbard (60) discusses the use of focused solar radiation pressure for attitude control; Villers and Olha (146) discuss the use of a solar sail to stabilize satellites and interplanetary probes.

   3. Gravity gradient effect

      The gravity gradient effect, which tends to torque the long axis of an elongated body towards the local vertical, can also be used for satellite attitude control. Kamm (70) describes a device—the Vertistat—for so utilizing this phenomenon.

VIII. Application to Aerospace Vehicles

Due to government security restrictions and corporate proprietary interests, relatively little information on specific attitude control systems is available in the academic literature.

A. Project Mercury

Twombly (142,143) and Zoeckler (162) describe the attitude control system for the Mercury capsule. Friona(45) describes the reliability testing of this system; Senders and Lindquist(125) describe the attitude display equipment used in the capsule.

B. Other satellite vehicles

Also mentioned in the literature is the attitude control of the Tiros satellites. Hecht and Manger (58) describe the magnetic torquing used; Siry and Nalvella (129) present the computer programs used in determining and controlling attitude for these satellites. The use of reaction wheels in the Nimbus satellites is described by Alexander (4); their use in both the Advent and Nimbus satellites is described in an anonymous article (105). Naumann (95) discusses observed disturbances affecting the attitude of the Explorer XI Satellite. Another anonymous article (20) describes the attitude control system for the Centaur vehicle.

C. Proposed space vehicles

Bucheim (11) examines a spin stabilization scheme for a proposed lunar probe; Kurzhals and Adams (79) and Olstad, Runberg, Blesser and Braun(98) describe attitude control systems for proposed manned space stations.

IX. Simulation and Human Factors

These two aspects of attitude control are closely related and are usually treated together in the literature.

A. Simulation studies

Carlisle (19) describes the three-axis simulator testing of an attitude control system using a combination of reaction wheels and reaction jets. Simulation studies of a system using body-mounted sensors and a single body-mounted reaction jet are summarized by Garner and Reid (49); similar studies of the simulation of command reaction controls are discussed by Hollman and Stillwell (62). Olstead, Runberg, Blesser and Braun(98) describe an inertial simulator for studying the attitude control of a spinning manned space station. The use of a fixed-base three-degrees-of-freedom simulator to study minimum manual control of attitude is examined by Bauerschmidt (6); the use of such a simulator to study the effects of the distribution of moments of inertia in a space station is investigated by Besco, Bauerschmidt and McElwain (8).

B. Role of human operator in attitude control

Ritchie and Hames (108) study the effect of attitude control arrangement on a pilot's ability to stop the spin of a simulated orbital vehicle. Human factors research on the Mercury capsule attitude control is described by Senders and Lindquist (125).

X. Additional Sources of Information

Further information on attitude control can be found in the general studies on this subject.

A. General attitude control surveys

The earliest of these are the surveys by Roberson (110,114,115) in 1960. Other general studies on the subject of attitude control are those by Haeussermann (55), by De Lisle, Hildebrant and Petranic (31,32), and by Dzilvelis, Kovba and Mason (35), in 1961, and by Stewart (133,134), Roberson (113) and Ergin, Norum and Windeknecht (37,38,39), in 1962.

B. Satellite attitude control surveys

Satellite attitude control is treated by Savet (120), by Kershner and Newton (74), by White and Pappas (152), and by Cole, Eckstrand and O'Neil (22) in 1961. Whitford (154) presented a brief discussion of satellite attitude control in the following year. Jennings, together with Knights (76), and with Hall (67), discusses the integration of the attitude control system with other spacecraft control systems.

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42. FREED, L. E.
ATTITUDE CONTROL SYSTEM FOR A SPINNING BODY.
ARS Journal, 32:396-401, March 1962.

The system described can stabilize the spin axis under the influence of load torque impulses torque loads and its performance is compared with that of a similar control system for a nonspinning body.

43. FREED, L. E.
ATTITUDE CONTROL SYSTEM FOR A SPINNING SATELLITE.
Institute of the Aerospace Sciences, American Rocket Society Paper No. 61-207-1901, presented at the IAS-ARS Joint National Meeting, Los Angeles, California, 13-16 June 1961. 28 pages.

The system described can accurately stabilize the attitude of the spin axis under the influence of load torque impulses. Analyzes the transient response and steady state behavior of the system under various loading conditions and compares the spinning body control system with the nonspinning body system.

44. FREY, E. J.
ATTITUDE CONTROL FOR AN UNMANNED INTERPLANETARY VEHICLE.
Massachusetts Institute of Technology, Instrumentation Laboratory, District Papers/60-682, Presented at the 1960 Great Lakes District Meeting.

An examination of the attitude control system required for accurate, self-contained interplanetary navigation indicates that most effective results could be obtained by a relatively simple set of individual devices connected by a flexible digital computer.

45. FRIONA, A. J.
RELIABILITY TESTING OF THE MERCURY CAPSULE ATTITUDE CONTROL SYSTEM.
In Institute of the Aerospace Sciences, Aerospace Support and Operations Meeting, Orlando, Florida, 4-6 December 1961, Proceedings, pages 167-170. New York: The Institute. 1962.

46. FROELICH, R. W. and H. PATAPOFF
REACTION WHEEL ATTITUDE CONTROL FOR SPACE VEHICLES.
Institute of Radio Engineers, Transactions on Automatic Control, AC-4:139-149, December 1959.

Describes a laboratory model of a single axis attitude control system utilizing intertial wheels.

47. GAYLORD, R. S.
DIFFERENTIATING GAS JET FOR SPACE ATTITUDE CONTROL.
ARS Journal, 31:75-76, January 1961.

A differential gas jet-which can be used either alone or in conjunction with reaction wheel controls-is proposed to reduce limit cycle velocities below those ordinarily measurable by the control system.

48. GARBER, T. B.
THE PRECISION OF SPINNING BODIES DUE TO GRAVITATIONAL GRADIENT TORQUE.
Rand Corporation, Report No. RM-3191-PR, June 1962.

Obtains solutions for a spinning body with an arbitrary mass distribution and under various orbital and body-attitude initial conditions.

49. GARNER, H. D. and J.J.E. REID,JR.
SIMULATOR STUDIES OF SIMPLE ATTITUDE CONTROL FOR SPIN-STABILIZED VEHICLES.
National Aeronautics and Space Administration, Technical Note D-1395, September 1962.

The system described used body-mounted attitude-error sensors and a single body-mounted reaction-control jet-Results of simulation studies indicate the effectiveness of the system over a wide range of operating conditions.

50. GAYLORD, R. S. and W. N. KELLER
ATTITUDE CONTROL SYSTEM USING LOGICALLY CONTROLLED PULSES.
American Rocket Society, Paper No. 1921-61, presented at the ARS Guidance, Control and Navigation Conference, Stanford, California, 7-9 August 1961. 12 pages.

Describes a new type of pulsed-jet attitude control which utilizes a pulse torquing according to error limits, together with nonlinear damping of motion by means of phase-plane quadrant information.

51. GODET, S.
SELF-STABILIZING GYRO CONTROL SYSTEM FOR SPACE VEHICLES.
American Society of Mechanical Engineers, Paper No. 60-AV-51, presented at the American Society of Mechanical Engineers Meeting, 5-9 June 1960.

A control system uncorporating three single-degree-of-freedom gyros is used for attitude control. The flywheels used have fixed speed but movable spin axis.

52. GRASSHOFF, L. H.
A METHOD FOR CONTROLLING THE ATTITUDE OF A SPIN-STABILIZED SATELLITE.
ARS Journal, 31:646-649, May 1961.

The current in a coil placed around on the satellite with its magnetic axis paralled to the spin axis is switched to generate torques averaging zero about one transverse axis but having a net value about the other transverse axis.

53. GRUBIN, C.
A GENERALIZED TWO-IMPULSE SCHEME FOR REORIENTING A SPIN-STABILIZED VEHICLE.
American Rocket Society, Paper No. 1922-61, presented at the Ars Guidance, Control and Navigation Conference, Stanford, California , 7-9 August 1961. 13 pages.

Analyzes the dynamics of a generalized two-impulse scheme for attitude control of a symmetric, spin-stabilized vehicle.

54. HAEUSSERMANN, W.
COMPARISON OF SOME ACTUATION METHODS FOR ATTITUDE CONTROL OF SPACE VEHICLES.
Aerospace Engineering, 19:64-65, May 1960.

Describes how torques for attitude control can be created according to a translational acceleration method or according to a rotational acceleration method.

55. HAEUSSERMANN, W.
RECENT ADVANCES IN ATTITUDE CONTROL OF SPACE VEHICLES.
ARS Journal, 32:188-195, February 1962.

Surveys the state of the art of attitude controls for satellites and space vehicles as of late 1961. There are 100 references cited in the text.

56. HARRIS, C. J. and R. H. JOHNSON
AN EXPERIMENTAL EVALUATION OF SEVERAL ATTITUDE CONTROL CONCEPTS.
In Seventh Symposium on Ballistic Missile and Space Technology, United States Air Force Academy, 13-16 August 1962, Transactions, Volume 1, pages 169-209.

Several attitude control concepts have been considered for providing hypersonic re-entry vehicles with maneuvering capabilities. The attitude control concepts experimentally evaluated here involve the application of movable structures--fins, flaps, and rods--located on the surface of axisymmetric ballistic-type re-entry vehicles models. Prior to considering these models with control surfaces, experimental studies were conducted to determine the static stability characteristics of and shock layer properties about the bodies without controls. Similar studies were then conducted on these bodies with controls present. Also evaluated was a magnetohydrodynamic concept for generating attitude control forces.

57. HATCHER, N. M. and E. F. GERMANN, JR.
STUDY OF A PROPOSED INFARED HORIZON SCANNER FOR USE IN SPACE-ORIENTATION CONTROL SYSTEMS. APPENDIX-RADIATION TRANSFER AND SYSTEM SENSITIVITY.
National Aeronautics and Space Administration, Technical Note, D-1005, January 1962. 32 pages. 11 references.

The device described here detects the thermal radiation discontinuity at opposite horizons to produce an attitude error signal. This system is designed to be applicable to the Earth, Moon, Mars or Venus.

58. HECHT, E. and W. P. MANGER
MAGNETIC ATTITUDE CONTROL OF THE TIROS SATELLITE.
American Astronautical Society, Paper No. 62-44, presented at the AAS / Goddard Memorial Symposium on Torques and Attitude Sensing in Satellites, Washington, D. C.: 16-17 March 1962.

An investigation of the motions of the Tiros Satellite indicates that its spin axis was moving at a rapid rate due to a satellite dipole interaction with the earth's magnetic field. Attitude control methods are presented to correct this condition.

59. HENDERSON, V. N.
POWER SUPPLY SYSTEMS FOR SPACE TRAINERS.
Aeroneutronic, Aeromechanics Technical Communication, May 1962.

60. HIBBARD, R. R.
ATTITUDE STABILIZATION USING FOCUSED RADIATION PRESSURE.
ARS Journal, 31:844-843, June 1961.

61. HILTON, W. F. and B. STEWART
THE ADVANTAGES OF ATTITUDE STABILIZATION AND STATION KEEPING IN COMMUNICATIONS SATELLITE ORBITS.
British Institute of Radio Engineers Journal, 22:193-202, September 1961.

The use of attitude stabilization to minimize use of transmitting power. A satellite mass, for which the radiation flux at a specified distance is the same whether or not the satellite is stabilized, is shown to exist for a given antenna gain. Analysis of the dependence of this mass on antenna gain and satellite lifetime indicates the existence of an optimum vehicle size for which stabilization is most effective.

62. HOLLEMAN, E. C. and W. H. STILLWELL
SIMULATOR INVESTIGATION OF COMMAND REACTION CONTROLS.
NACA, RM H58D22, July 1958, 12 pages.

63. HUBBARD, E.
ROCKET THRUST CONTROL.
Engineering and Science Review, 5:14, January 1962.

Describes methods of thrust vector control, specific attention being given to secondary fluid injection.

64. HULTQUIST, P. F.
GRAVITATIONAL TORQUE IMPULSE ON A STABILIZED SATELLITE.
ARS Journal, 31:1506-1509, November 1961.

Computes angular impulse in pitch and roll imparted to a stabilized, jet-controlled, solar-oriented satellite which has one axis normal to the elliptic and a transverse axis along the solar vector and which is in either a circular or an elliptical orbit.

65. IVES, N. E.
THE EFFECT OF SOLAR RADIATION PRESSURE ON THE ATTITUDE CONTROL OF AN ARTIFICIAL EARTH SATELLITE.
Royal Aeronautical Establishment, Report No. TN G.W.570, April 1961. 46 pages.

If a satellite, assumed to have the shape of a rectangular prism and perfectly reflecting surfaces, has its center of mass identical with the center of symmetry of the external shell, an analysis of the torque produced about that the radiation-pressure about its center of mass is zero.

66. IVES, N. E.
PRINCIPLES OF ATTITUDE CONTROL OF ARTIFICIAL SATELLITES.
Ministry of Aviation, Aero-Nautical Research Council, London, England, R & M 3276, November 1959.

Derives equations of motion for small angular displacements from the equilibrium position of a satellite oriented towards earth; reaction-flywheel damping is used.

67. JENNINGS, A. and G. M. HALL
STUDY OF INTEGRATED CRYOGENIC FUELED POWER GENERATING AND ENVIRONMENTAL CONTROL SYSTEMS, VOLUME V: INTEGRATION AND CONTROL STUDIES.
Aeronautical Systems Division, Report No. ASD TR 61-327, Volume V, November 1961.

Discusses possible degrees of integration of the power generation, environmental control, cabin atmosphere control, attitude control and propellant storage systems in a space vehicle.

68. JUELICH, O. C.
PASSIVE AERODYNAMIC ATTITUDE STABILIZATION OF NEAR EARTH SATELLITES, VOLUME III: MATHEMATICAL TECHNIQUES AND COMPUTER PROGRAMMING.
Wright Air Development Division, Technical Report No. 61-133, Volume III, July 1961.

Describes a computer program for the numerical integration of the pitch equation of an aerodynamically stabilized satellite.

69. KAMM, L. J.
MAGNETORQUER - A SATELLITE ORIENTATION DEVICE.
ARS Journal, 31:813-15, June 1961.

This device generates a torque by the action of the terrestial magnetic field on electric current in the satellite.

70. KAMM, L. J.
"VERTISTAT": AN IMPROVED SATELLITE ORIENTATION DEVICE.
ARS Journal, 32:911-913, June 1962.

The device described in this paper consists in a wire or tube at least 100 ft. long which extends from the satellite and provides a considerable movement of inertia about a transverse axis. The resultant erecting torque is of the magnitude of 500 dyne - cm. per degree. Two shorter secondary tubes provide passive damping.

71. KELLER, G. R.
FLIGHT CONTROL OF AEROSPACE VEHICLES.
Journal of the Aerospace Sciences, 29:233-234, February 1962.

The performance of a Schuler-tuned inertial guidance system near the surface of the earth is studied. Results indicate that position amplitude error-due either to random acceleration of random platform - drift - rate errors-- is in direct proportion to the square root of the power spectral density of the error output at zero frequency.

72. KENDALL, P. E. and R. E. STALCUP
ATTITUDE REFERENCE DEVICES FOR SPACE VEHICLE.
Institute of Radio Engineers, Proceedings, 48:765-770, April 1960.

Describes an attitude sensing device using two narrow infrared scanning beams to aid in establishing a vertical reference line from a space vehicle in orbit to the planet about which it is orbiting.

73. KENNEDY, H. B.
A GYRO MOMENTUM EXCHANGE DEVICE FOR SPACE VEHICLE ATTITUDE CONTROL.
Institute of the Aerospace Sciences, Paper No. 62-88, presented at the Institute of the Aerospace Sciences National Summer Meeting, Los Angeles, California, 19-22 June 1962. 54 pages.

Describes a gyro control device for use in attitude control systems requiring momentum exchange devices, employing only two gyro wheels and two gimbals to control the three components of vehicular rate.

74. KERSHNER, R. B. and R. R. NEWTON
ATTITUDE CONTROL OF ARTIFICIAL SATELLITES.
<u>In</u> Liller, W., editor, Space Astrophysics, pages 205-227.
New York: McGraw-Hill. 1961.

75. KLASS, P. J.
NEW GYRO TECHNIQUE ORIENTS SATELLITE.
Aviation Week and Space Technology, 76:68-73, 12 February 1962.

Describes a semi-passive stabilization technique which uses the inherent gyroscopic properties of a satellite to keep the satellite oriented towards earth.

76. KNIGHTS, A. and A. JENNINGS
STUDY OF INTEGRATED CRYOGENIC FUELED POWER GENERATING AND ENVIRONMENTAL CONTROL SYSTEMS, VOLUME IV: ENVIRONMENTAL CONTROL AND ATTITUDE CONTROL STUDIES.
Aeronautical Systems Division, Report ASD TR 61-327, Volume IV, November 1961.

An investigation of methods for integrating environmental control and attitude control functions with space vehicle auxiliary power systems indicates that an intermediate coolant is necessary between the heat sources and the cryogenic heat sinks.

77. KOOP, R. E. and R. J. WHITE
A CONTROL SCHEME FOR ATTITUDE CONTROL OF LARGE FLEXIBLE BOOSTERS.
Society of Automotive Engineers, Preprint No. 429 C, presented at the SAE National Aeronautical and Space Engineering and Manufacturing Meeting, Los Angeles, California, 9-13 October 1961. 7 pages.

78. KOVIT, B.
REMOTE SPIN AND ATTITUDE CONTROL FOR SYNCOM.
Space/Aeronautics, 37:77-79, February 1962.

Describes orbital characteristics, together with antenna pattern and gain, of a stationary communications repeater using ground-controlled spin stabilization and attitude control.

79. KURZHALS, P. R. and J. J. ADAMS
DYNAMICS AND STABILIZATION OF THE ROTATING SPACE STATION.
Astronautics, 7:25-29, September 1962.

To minimize wobbling motion in a rotating space station the attitude errors and wobbling motion resulting from applied disturbances must be determined and defined. In addition, damping and attitude control systems capable of minimizing undesirable motion while maintaining required orientation must be devised and tested.

80. LEE, E. B.
DISCUSSION OF SATELLITE ATTITUDE CONTROLS.
ARS Journal, 32:981-982, June 1962.

Reaction jets are used to achieve attitude control in two steps:
1) bringing angular velocity to zero by reaction jets,
2) using smaller jets or momentum changes to maintain attitude.

81. LELIAKOV, I. P. and T. A. SAVO
COMMUNICATION SATELLITE ATTITUDE CONTROL. (TITLE UNCLASSIFIED). CONFIDENTIAL.
In Seventh Symposium on Ballistic Missile and Space Technology, U. S. Air Force Academy, 13-16 August 1962, Transactions, Volume 4, pages 231-291.

82. LEVINE, S. E.
SUMMARY OF COMMUNICATION SATELLITE SYSTEMS. (TITLE UNCLASSIFIED). SECRET.
Aerospace Corporation, Document No. AS-62-0000-01794, 9 March 1962.

83. LIEBERMAN, S. I.
A BANG-BANG ATTITUDE CONTROL SYSTEM FOR SPACE VEHICLES.
Aerospace Engineering, 21:54-55,64,65,68, October 1962.

A mathematical model of a bang-bang reaction jet attitude control system is derived on the basis of conditional switching techniques. A comparison of the actual and theoretical performance of the system indicates that a desired attitude change can be obtained in a minimum amount of time.

84. MACKAY, J. S.
APPROXIMATE SOLUTION FOR ROCKET FLIGHT WITH LINEAR TANGENT THRUST CONTROL.
ARS Journal, 30:1091-1093, November 1960.

An approximate solution to the equations of motion, involving linear-tangent thrust attitude control, is evaluated by comparing it with accurate numerical integration; results of this evaluation indicate that it not only possesses sufficient accuracy for preliminary calculation for boost vehilces but is four times more rapid than equally accurate numerical integration techniques.

85. MAES, M. E.
PARALLEL RAILS PROPOSED FOR ATTITUDE CONTROL.
Missiles and Rockets, 10:34-36, February 1962.

Describes pulsed plasma accelerator and compares its effectiveness for attitude control systems with that of arc jets and ion engines.

86. MARGULIES, G. and G. S. GOODMAN
DYNAMICAL EQUATIONS FOR THE ATTITUDE MATRIX OF AN ORBITING SATELLITE.
ARS Journal, 32:1414, September 1962.

A system of dynamic equations for the components of a time--varying rotation matrix deriving the attitude motion of an orbiting satellite is derived in terms of the principal moments of inertia of the satellite and the body components of its external torque field.

87. MC ILVAIN, R. J.
EFFECTS OF SOLAR RADIATION PRESSURE UPON SATELLITE ATTITUDE CONTROL.
American Rocket Society, Paper No. 1918-61, presented at the ARS Guidance, Control and Navigation Conference, Stanford, California: 7-9 August 1961. 26 pages.

An examination of the effect of solar radiation developed torques on both spin-stabilized and actively earth-oriented satellites indicates that solar pressure may cause either periodic torques or torques constant with respect to inertial space. The type of torque produced depends on a number of elements.
1) orbital inclination to the ecliptic plane,
2) orientation requirements,
3) vehicle configuration

88. MC ILVAIN, R. J.
SATELLITE ANGULAR MOMENTUM REMOVAL UTILIZING THE EARTH'S MAGNETIC FIELD.
American Astronautical Society, Paper No. 62-53, presented at the AAS/ Goddard Memorial Symposium on Torques and Attitude Sensing in Satellites, Washington, D. C., 15-16 March 1962.

Developes general constraints for removing the stored angular momentum. Controlled interactions of body-fixed magnetic current loops with the earth's magnetic field are used to achieve this. The concept is applied to the design of an earth tracking satellite on a 300 nautical mile arcular orbit.

89. MC MORROW, D. R., C. A. BROWNLEE, S. DADRADRIAN and H. SCHWARTZ
A PRECISION STAR-TRACKER FOR SPACE VEHICLE ATTITUDE CONTROL AND NAVIGATION.
American Rocket Society, Paper No. 1930-61, presented at the ARS Guidance, Control and Navigation Conference, Stanford, California , 7-9 August 1961 .14 pages.

Describes in detail the components of a star-tracker which can locate and locks on a star anywhere within a 30 degree cone-of-view, and can measure the angle between the line to the star and a reference plane with degree of error less than 10 seconds of arc.

90. MC RUER, D. T. and R. L. STAPLEFORD
POWER AND ENERGY REQUIREMENTS FOR A FIXED-AXIS INERTIA WHEEL ATTITUDE CONTROL SYSTEM.
ARS Journal, 31:665-668, May 1961.

Developes approximate transfer functions for a single-axis attitude control system using a fixed axis inertia wheel, and uses these functions to derive expressions for the power required to drive the wheel and the energy expended by the driver.

91. MICHELSON, I.
COUPLING EFFECTS OF GRAVITY-GRADIENT SATELLITE MOTIONS.
ARS Journal, 32:1735, November 1962.

Communications satellite in circular orbits for long periods exhibit dynamic characteristics that are controllable in attitude; this note discusses an unexpected coupling of rotary vibration modes.

92. MOAK, H.
THRUST-VECTOR-CONTROL SCHEMES FOR SOLID-PROPELLANT ROCKETS.
Astronautics, 7:28-29,62, March 1962.

Describes the following methods of steering a large solid-propellant vehicle:
1) single-axis hinged nozzle,
2) secondary injection,
3) omni-axis hinged nozzle,
4) plug nozzle,
5) jet vanes,
6) jetavators,
7) rotating nozzle,
8) ancillary motions,
9) mechanical wedge.

93. MOORE, R. L. and H. E. THOMASON
GIMBAL GEOMETRY AND ATTITUDE SENSING OF THE ST-124 STABILIZED PLATFORM.
National Aeronautics and Space Administration, Technical Note D-1118, May 1962.

Describes study to obtain attitude signals from a four-gimbal platform. A mimimum number of resolvers were required to furnish roll, yaw and pitch attitude signals within an accuracy of six minutes of arc.

94. MORTENSEN, R. E.
DESIGN CONSIDERATIONS OF INERTIA WHEEL SYSTEMS FOR ATTITUDE CONTROL OF SATELLITE VEHICLES.
Instrument Society of America, Transactions, 1:101-110, January 1962.

This paper analyzes the problem of determining the momentum resorvoir capacity required for attitude control, together with a suitable control scheme for this application.

95. NAUMANN, R. J.
AN INVESTIGATION OF THE OBSERVED TORQUES ACTING ON EXPLORER XI.
American Astronautical Society, Paper No. 62-46, presented at the AAS/Goddard Memorial Symposium on Torques and Attitude Sensing in Satellites, Washington, D. C., 16-17 March 1962.

Discusses orientation analysis methods based on observed radio strength patterns, together with various mechanisms causing external torques.

96. NICKLAS, J. C. and H. C. VIVIAN
DERIVED-RATE INCREMENT UTILIZATION: ITS APPLICATION TO THE ATTITUDE CONTROL PROBLEM.
American Society of Mechanical Engineers, Transactions, Series D, (Journal of Basic Engineering), 84:54-60, March 1962.

A gyro-free nonlinear system with derived-rate feedback is proposed for spacecraft attitude control; the system uses cold-gas on-of actuations and has a dead zone and hysteresis to mimimize noise effects.

97. OLDS, R. H.
ATTITUDE CONTROL AND STATION KEEPING OF A COMMUNICATION SATELLITE IN A 24-HOUR ORBIT.
American Rocket Society, Paper No. 2372-62, presented at the ARS Electric Propulsion Conference, Berkeley, California, 14-16 March 1962. 32 pages. 21 references.

Weight, power, thrust and duty-cycle requirements are compared for cesium and mercury ion propulsion systems proposed for attitude control of a solar-powered communications satellite over a two-year lifetime.

98. OLSTAD, M. D., R. G. RUNBERG, W. BLESSER and L. BRAUN JR.
A SPINNING MANNED SPACE STATION SYNTHESIS AND MECHANIZATION OF THE ATTITUDE CONTROL SYSTEM.
American Rocket Society, Paper No. 1923-61, presented at the ARS Guidance, Control and Navigation Conference, Stanford, California, August 7-9, 1961. 11 pages.

Describes an inertial simulator for studying attitude control for a spinning manned space station.

99. ONE-HALF-OZ LIQUID PROPELLANT ROCKET FOR ORBIT CORRECTION.
Aviation Week and Space Technology, 76:59, 1 January 1962.

Describes Microrocket--a liquid propellant rocket producing from one hundredth to one-tenth of a pound of thrust to meet performance and weight requirements between plasma jets and cold gas jets--being developed by Aerojet.

100. ORINSBY, R. D. and M. C. SMITH
CAPABILITIES AND LIMITATIONS OF REACTION SPHERES FOR ATTITUDE CONTROL.
ARS Journal, 31:808-812, June 1961.

Discusses characteristics of an electrically suspended reaction sphere as an attitude control device for space vehicles.

101. PATAPOFF, H.
APPLICATION OF THE RATE DIAGRAM TECHNIQUE TO THE ANALYSIS OF SPACE VEHICLE ON-OFF ATTITUDE CONTROL SYSTEMS.
American Rocket Society, Paper No. 1924-61, presented at the ARS Guidance, Control and Navigation Conference, Stanford, California, 7-9 August 1961. 16 pages.

Describes use of a plot of angular rate of control torque removal versus the rate of torque application to analyze the performance of space vehicle control systems.

102. PEMBERTON, J. D.
HIGH TEMPERATURE PNEUMATIC SYSTEMS CONTROL MISSILE ATTITUDE.
Automatic Control, 15:22-27, August 1961.

Describes various types of hot-gas control systems, open-center, closed-center, on-off and proportional together with combinations of the sensors and control systems.

103. PETERS, R. A., R. A. KOVACEVICH and D. GRAHAM
SINGLE-AXIS ATTITUDE REGULATION OF EXTRA-ATMOSPHERIC VEHICLES. APPENDIX A- THE USE OF TIME DELAY TO REPRESENT SYSTEM LAGS IN PHASE PLANE ANALYSIS OF SWITCHING CONTROL SYSTEMS. APPENDIX B- DEVELOPMENT OF TRAJECTORY EQUATIONS FOR SECOND ORDER CONTROLLED ELEMENTS.
Aeronautical Systems Division, Technical Report No. 61-129, February 1962. 247 pages.

The linear control of a space vehilce, in which the automatic control systems use inertial wheels and/or mass ejection, is analyzed upon the basis of simplified three-degree-of freedom rational equations of motion.

104. PETERSON, P. W. and L. O. STIMPSON
WEIGHT AND ORBIRAL LIFETIME ESTIMATES FOR SPACE TRAINERS.
Ford Motor Company, Aeroneutronics Division, Aeroneutronic, Technical Note, MS-07A, December 1961.

105. REACTION WHEELS FOR ADVENT AND NIMBUS ATTITUDE.
Space/Aeronautics, 38:159, 1961, November 1962.

Describes the development of reaction wheels which will enable an active satellite to maintain or change its attitude on command.

106. REICH, A.
ATTITUDE DETERMINATION—A NEW DIMENSION FOR RADAR.
Institute of Radio Engineers, 1962 National Winter Convention of Military Electronics, Los Angeles, California, 7-9 February 1962, Conference Proceedings, page 105-107. New York: The Institute: 1962.

Describes method for determining space vehicle attitude from measurements made with ground equipment. Attitude determination will be obtained by suitable coding of the radiation lobes transmitted from the vehicle and will require only electronic equipment aboard the vehicle itself.

107. REITER, G. S. and W. T. THOMPSON
ROTATIONAL MOTION OF PASSIVE SPACE VEHICLES.
American Astronautical Association, Paper No. 62-42, presented at the AAS/Goddard Memorial Symposium on Torques and Attitude Sensing in Satellites, Washington, D. C., 16-17 March 1962.

Discusses the following two methods for attitude stabilization of passive spinning satellites by internally-produced forces alone:
1) removal of precessional motion from stable satellites by using dampers,
2) delaying tumbling in unstable satellites by minimizing internal dampling.

108. RITCHIE, M. L. and L. F. HANES
MANUAL ATTITUDE CONTROL IN SPACE--ARRANGEMENT OF CONTROLS.
American Society of Mechanical Engineers, Paper 60-SA-34, presented at the American Society of Mechanical Engineers Summer Annual Meeting, Dallas, Texas, 5-9 June 1960.
7 pages.

Describes experimentation to determine the effect of the arrangement of controls to stop the spin of a simulated orbital vehicle. Results indicate that grouping of the controls-for operation by one hand, one hand and two feet, or two hands and two feet-made no practical difference in performance.

109. ROACH, J. E. and R. J. SEYMOUR
SPHERICAL ROCKETS FOR SPACE VEHICLE ATTITUDE AND VELOCITY CONTROL.
American Rocket Society, Paper No. 2241-61, presented at the Space Flight Report to the Nation, New York, New York: 9-15 October 1961.

The Thiokol TE-345 solid propellant rocket motor described is a gumballed spherical vernier motor possessing both impulse and thrust vector control.

110. ROBERSON, R. E.
ATTITUDE CONTROL OF SATELLITES AND SPACE VEHICLES.
In Ordway, F. I., III, Advances in Space Science, Volume II, pages 351-436. New York: Academic Press. 1960.

An excellent summary, as of mid-1960, of the state-of-the-art of attitude sensing and control.

111. ROBERSON, R. E.
ATTITUDE REFERENCE AS ESTABLISHED BY A HORIZON SCANNER.
Journal of the Astronautical Sciences, 9:86-88, Fall 1962.

A horizon scanner and certain requirements on the forward direction define an attitude reference frame developed by Air Force-sponsored, research. The motion of this reference frame introduces inertial reaction torque disturbances into the system, but there is no systematic sensor error relative to the frame itself.

112. ROBERSON, R. E.
GRAVITY GRADIENT DETERMINATION OF THE VERTICAL.
ARS Journal, 31:1509-1515, November 1961.

Detailed formulation and mechanization possibilities of the analytical principles of differential accelerometer gravity gradient sensors.

113. ROBERSON, R. E.
THE IDENTITY OF TWO DESCRIPTIONS OF ATTITUDE MOTIONS.
Journal of the Astronautical Sciences, 9:106-107, Winter 1962.

Describes two fundamental equations for the attitude motions of a satellite or space vehicle. These equations differ in their choice of base points. The first does not have a fixed base point, being the composite center of mass of the collection of rigid bodies within the vehicle, the second does have a fixed base point.

114. ROBERSON, R. E.
METHODS FOR THE CONTROL OF SATELLITES AND SPACE VEHICLES.
II. CONTROL SYSTEM MECHANIZATION AND ANALYSIS.
Wright Air Development Division, Technical Report No. 60-643, Volume II, 31 July 1960, 295 pages. 194 references.
AD 250 270

A general survey of space vehicle attitude control systems, including a review of the literature.

115. ROBERSON, R. E.
ON GUIDANCE AND CONTROL REQUIREMENTS IN ASTRONAUTICS.
Franklin Institute Journal, 269:196-220, March 1960.

Includes discussion of attitude control problems.

116. ROCKETS STEERED BY SECONDARY INJECTION.
SAE Journal, 70:82-83, February 1962.

Describes thrust vector methods in current use, including a new method, secondary injection.

117. SALMIRS, S., S. L. KESSLER and O. J. PARKER
A SIMPLE SOLAR ORIENTATION CONTROL SYSTEM FOR SPACE VEHICLES.
National Aeronautics and Space Administration, Technical Note D-1271, September 1962.

The response of the system to various initial errors was measured on a single-degree-of-freedom air-bearing platform and phase-plane diagrams of system performance presented. An investigation of applying control torques and artificial damping indicate that a simple system is obtainable by using reaction jets.

118. SATYENDRA, K. N. and R. E. BRADFORD
SELF-CONTAINED NAVIGATIONAL SYSTEM FOR DETERMINATION OF ORBITAL ELEMENTS OF A SATELLITE.
ARS Journal, 31:949-956, July 1961.

Satellite attitude is sensed by means of a prime reference and is used to develope a theory for determining the six orbital elements of a satellite. The prime reference is itself established by taking direct measurements of the local geocentric vertical over a period of time with a horizon tracker and combining this data with that obtained from a pair of star trackers.

119. SAVET, P. H.
ATTITUDE CONTROL OF ORBITING SATELLITES AT HIGH ECCENTRICITY.
ARS Journal, 32:1577-1582, October 1962.

120. SAVET, P. H.
ATTITUDE CONTROL OF ORBITING SATELLITES AT HIGH ECCENTRICITY.
ARS, Paper No. 1919-61, presented at the ARS Guidance, Control and Navigation Conference, Stanford, California, 7-9 August 1961. 16 pages.

Current satellite attitude control methods are discussed and space vehicle equations of motion are reviewed.

121. SAVET, P. H.
SATELLITE ATTITUDE - DETECTION AND CONTROL.
ARMA Engineering, 3:4-9, November 1960.

Gradient accelerometer techniques are discussed from the viewpoint of their possible application to attitude control in artificial satellites.

122. SAVO, T. A. and I. P. LELIAKOV
CHARACTERISTICS OF THE ADVENT ATTITUDE CONTROL SYSTEM. (TITLE UNCLASSIFIED). CONFIDENTIAL.
Aerospace Corporation, Report No. 1951-158, December 1961.

123. SCHMIDLIN, A. E.
GAS SYSTEM DEVELOPMENTS.
Hydraulics and Pneumatics, 14:72-73, December 1961.

Gas systems for space vehicle attitude controls are discussed.

124. SCHRELLO, D. M.
PASSIVE AERODYNAMIC ATTITUDE STABILIZATION OF PASSIVE EARTH SATELLITES. I- LIBRATIONS DUE TO COMBINED AERODYNAMIC AND GRAVITATIONAL TORQUES. APPENDIX A-GRAVITATIONAL TORQUES ON A RIGID BODY. APPENDIX B-EXPANSION OF COEFFICIENTS IN EQUATIONS OF ANGULAR MOTION. APPENDIX C-EFFECTS OF AERODYNAMIC DRAG AND DAMPING ON THE MOTION OF NEAR EARTH SATELLITES.

Wright Air Development Division, Technical Report No. 61-133, Volume 1, July 1961, 159 pages, 37 references.

Investigates general equations governing angular motion for a rigid satellite where both gravitational and aerodynamic torques are included and where there is a spherically symmetric but rotating atmosphere.

125. SENDERS, J. W. and O. H. LINDQUIST
EARLY DEVELOPMENT OF A VEHICLE ATTITUDE DISPLAY AND CONTROL.
American Rocket Society, Paper No. 1400-60, presented at the ARS 15th Annual Meeting, Washington, D. C., 5-8 December 1960.

Description of human factors research conducted by Minneapolis-Honeywell on Project Mercury.

126. SENTMAN, L. H.
COMPARISON OF THE EXACT AND APPROXIMATE METHODS FOR PREDICTING FREE MOLECULE AERODYNAMIC COEFFICIENTS.
ARS Journal, 31:1576-1579, November 1961.

Discusses exact and approximate methods for computing forces and movements of near-earth satellites caused by molecular impingment, including effect on attitude control.

127. SINGER, S. F.
FORCES AND TORQUES DUE TO COULOMB INTERACTION WITH THE MAGNETOSPHERE.
American Astronautical Society, Paper No. 62-50, presented at the AAS/Goddard Memorial Symposium on Torques and Attitude Sensing in Satellites, Washington, D. C., 16-17 March 1962.

Studies interaction of electric charge on a body in space with the inionized gas of the magnetosphere, which produces and electric drag force and affects passive and active attitude control.

128. SINGER, S. F.
A MIMIMUM ORBITAL INSTRUMENTED SATELLITE - NOW.
British Interplanetary Society Journal, 13:74-79, March 1954.

Discusses spin stabilization as a means of attitude control of small, unmanned satellites.

129. SIRY, J. W. and J. V. NALVELIA
ATTITUDE DETERMINATION FOR THE TIROS SATELLITES.
In Association for Computing Machinery, 16th National Meeting, Los Angeles, California, 5-8 September 1961, Preprints, Paper No. 13C-2. 4 pages.

Describes IBM 7090 computer programs connected with attitude systems of satellites.

130. SKLAR, S. J.
PERTURBATION ANALYSIS FOR ORBITAL ATTITUDE CONTROL.
Space/Aeronautics, 38:83-93, November 1962.

Applies an analysis of satellite dynamics, as affected by disturbing torques, to satellite attitude-control system design. Developes a procedure for evaluating the principal disturbing torques, deriving the necessary orbital equations in a form that can be programmed on a digital computer. Disturbing torques are evaluated by determining the angular displacements produced on a satellite and then studying the perturbing effects of the various accelerations in terms of the satellite orbit.

131. SOBEY, A. F. and W. C. PATERSON
VECTROL SYSTEM CONTROLS ATTITUDE.
SAE Journal, 70:85, February 1962.

132. SOBEY, A. J. and W. C. PATERSON
ATTITUDE CONTROL SYSTEMS FOR SOLID PROPELLANT VEHICLES.
Society of Automative Engineers, Preprint No. 429A, presented at the SAE National Aeronautical and Space Engineering and Manufacturing Meeting, Los Angeles, California, 9-13 October 1961. 6 pages.

Describes theoretical performance of the Vectrol attitude control system.

133. STEWART, I. B.
SATELLITE ATTITUDE CONTROL. I.
Control, 5:84-89, April 1962.

Surveys space-vehicle attitude control problems and the techniques used in solving these problems.

134. STEWART, B.
SATELLITE ATTITUDE CONTROL. II.
Control, 5:145-148, May 1962.

Discusses satellite stabilization dynamics, giving equations for passive stabilization and methods of damping.

135. STILLWELL, W. H. and H. N. DRAKE
SIMULATOR STUDIES OF JET REACTION CONTROLS FOR USE AT HIGH ATTITUDE.
NACA, RM H58G18A, September 1958. 40 pages.

Investigates use of pilot-controlled jet reaction forces for vehicle control in regions of extremely low dynamic pressure--effects of various control configurations, control magnitudes, control techniques, dynamic pressure, and aerodynamic stability. Results of analog computer and mechanical simulator tests indicate that control techniques are somewhat different from those used with aerodynamic controls at flight speeds and that constant attention to the control tasks is required.

136. STIMPSON, L. D.
ATTITUDE CONTROL REQUIREMENTS FOR SPACE TRAINERS.
Ford Motor Company, Aeroneutronics Division, Aeromechanics, Technical Communication, March 1962.

137. STUART, W. H.
SATELLITE ATTITUDE STABILIZATION BY MEANS OF FLYWHEELS.
Aerospace Engineering, 20:10-11, 64-72, September 1961.

138. THOMASON, H. E.
SATURN VEHICLE ATTITUDE RESOLVER COMPUTER ERROR ANALYSIS.
National Aeronautics and Space Administration, Technical Note D-1119, September 1962.

Describes an investigation of maximum root sum square attitude error from the ST-124 inertial platform used for the Saturn C-1 vehicle.

139. THOMSON, W. T.
SPIN STABILIZATION OF ATTITUDE AGAINST GRAVITY TORQUE.
Journal of the Astronautical Sciences, 9:31-33, Spring 1962.

Discusses amount of spin required to stabilize a satellite when its attitude has become unstable due to gravity torque.

140. TINLING, B. E.
MEASURED STEADY-STATE PERFORMANCE OF WATER VAPOR JETS FOR USE IN SPACE VEHICLE ATTITUDE CONTROL SYSTEMS.
National Aeronautics and Space Administration, Technical Note D-1302, May 1962, 20 pages.

Several nozzles, with thrusts up to 1000 dynes, were measured for steady-state performance in a vacuum. The variation of specific impulse and thrust coefficient with expansion ratio can be predicted by calculations based on one-dimensional isentropic flow, and is dependent upon the nozzle diameter.

141. TRAYNELIS, K. A. and D. L. RYAN
HOT GAS CONTROL SYSTEMS. III-USING REACTION TO CONTROL VEHICLE ATTITUDE.
Control Engineering, 8:109-114, July 1961.

Discusses factors involved in choosing a control method and propellant for reactive control systems in vehicles operating beyond the limits of aerodynamic control surface effectiveness.

142. TWOMBLY, J. W.
THE MERCURY CAPSULE ATTITUDE CONTROL SYSTEM.
In Institute of the Aerospace Sciences, National Meeting on Manned Space Flight, St. Louis, Missouri, 30 April, 2 May 1962, Proceedings, pages 228-231. New York: The Institute. 1962.

Describes the integrated manual and automatic systems for controlling the attitude of the capsule.

143. TWOMBLY, J. W.
THE MERCURY CAPSULE ATTITUDE CONTROL SYSTEM.
Navigation, 9:237-244, Autumn 1962.

144. VAETH, J. E.
FLYWHEEL CONTROL OF SPACE VEHICLES.
Institute of Radio Engineers, International Convention Record, Volume 9, Part 4, pages 91-103, 1960.

Presents the results of a three-axis analog computer study of the flywheel auto-pilots for space vehicle attitude control.

145. VAETH, J. E.
VAPOR JET CONTROL OF SPACE VEHICLES.
Institute of Radio Engineers, Transactions on Automatic Control, AC-7:67-74, October 1962.

The reaction-jet attitude-control technique described allows an extremely low thrust magnitude to be achieved by releasing small amounts of fuel at a time to vaporize in the vacuum surrounding the satellite or space vehicle.

146. VILLERS, P. and W. OLHA
A SOLAR SAIL ATTITUDE STABILIZES FOR SATELLITES AND INTERPLANETARY PROBES. APPENDIX I-RESTORING TORQUE ON SELF STABILIZING SECTION. APPENDIX II-OSCILLATION DAMPING WITH THE SELF STABILIZED STABILIZER.
American Rocket Society, Paper No. 2251-61, presented at the Space Flight Report to the Nation, New York, New York, 9-15 October 1961. 7 pages.

147. WAI CHAO, W.
HOT-GAS SYSTEMS CONTROL ATTITUDE IN EXTREME ENVIRONMENTS.
Space/Aeronautics, 35:65-66,69 March 1961.

148. WAI CHAO, W.
JET REACTION SYSTEMS FOR ATTITUDE CONTROL.
Hydraulics and Pneumatics, 14:70-71, December 1961.

Discusses use of biopropellant, monopropellant and solid-propellant energy sources for attitude control jet reaction systems in space vehicles.

149. WHITE, J. B.
METEORIC EFFECTS ON ATTITUDE CONTROL OF SPACE VEHICLES.
ARS Journal, 32:75-78, January 1962.

Applies to the 24-hour communication satellite general methods developed for determining meteoric disturbance to the various types of space vehicle configurations.

150. WHITE, J. S. and W. N. HANSEN
STUDY OF A SATELLITE ATTITUDE CONTROL SYSTEM USING INTEGRATING GYROS AS TORQUE SOURCES.
NASA, TN D-1073, September 1961. 37 pages.

Derives some general design criteria and applies them to a specific example. Compares the results of the analytical design with those of an analog computer and with experimental results from a low-friction platform. Results indicate that the steady-state and transient behavior of the system using single-degree-of-freedom integrating gyros was reasonably good. Gyros have a major advantage in use for torque forces in that the gyros also act to stabilize the vehicle directly, even in the absence of an external reference. Thus, when the target is occulted, no alternate reference is needed.

151. WHITE, J. S. and Q. M. HANSEN
STUDY OF SYSTEMS USING INERTIA WHEELS FOR PRECISE ATTITUDE CONTROL. APPENDIX A-VELOCITY AND TORQUE INPUTS. APPENDIX B-ANALYSIS OF AN INTEGRATING-GYRO SYSTEM. APPENDIX C-COMPLETE MOTOR AND WHEEL BLOCKS DIAGRAM.
National Aeronautics and Space Administration, Technical Note D-691, April 1961. 72 pages.

152. WHITE, J. S. and J. S. PAPPAS
GENERAL CONSIDERATIONS FOR SATELLITE ATTITUDE CONTROL SYSTEMS.
Institute of the Aerospace Sciences, Paper No. 61-19, presented at the IAS 29th Annual Meeting, New York, New York. 23-25 January 1961. 22 pages.

The role of constant gain and differentiating torquers in satellite attitude control is discussed.

153. WHITE, J. S., F. H. SHIGEMOTO and K. BOURQUIN
SATELLITE ATTITUDE CONTROL UTILIZING THE EARTH'S MAGNETIC FIELD. APPENDIX-DERIVING OF THE EARTH'S MAGNETIC FIELD AS A FUNCTION OF SATELLITE COORDINATES.
NASA, TN D-1068, August 1961. 38 pages.

Uses the torque developed by the interaction of current-carrying coils with the earth's magnetic field as a means of attitude control. The degree to which vehicle attiutde can be thus maintained depends on the fluctuations of the magnetic field at the satellite as the satellite orbits about the earth. Due to the nature of the torque developed only two vehidle axes can be continuously controlled simultaneously.

154. WHITFORD, R. K.
ATTITUDE CONTROL OF EARTH SATELLITES. I-SOURCES OF TORQUE.
Control Engineering, 9:93-97, February 1962.

The following means of attitude control are described:
1) spin stabilization,
2) use of natural scurces of torque,
3) stored momentum,
4) expulsion of mass.
In addition, a technique combining stored momentum and expulsion of mass is examined.

155. WHITFORD, R. K.
ATTITUDE CONTROL OF EARTH SATELLITES. II-SENSING AND MODES OF CONTROL.
Control Engineering, 9:97-101, April 1962.

Discusses the following methods for sensing attitude:
1) fixed field of view scanning in a cone,
2) use of an edge tracker to locate and track the horizon in a fixed plane,
3) use of a passive scanner employing a wide field of view imaged on a detector array.

156. WILLIAMS, D. D.
TORQUES AND ATTITUDE SENSING IN SPIN-STABILIZED SYNCHRONOUS SATELLITES.
American Astronautical Society, Paper No. 62-43, presented at the AAS/Goddard Memorial Symposium on Torques and Attitude Sensing in Satellites, Washington, D. C., March 16-17, 1962.

A compression of spin stabilization with three-axis attitude control indicates that the former is most practical at the present stage of booster development.

157. WILSON, R. H.
EXPLORTATION OF MAGNETIC TORQUES ON SATELLITES.
American Astronautical Society, Paper No. 62-51, presented at the AAS/Goddard Memorial Symposium on Torques and Attitude Sensing in Satellites, Washington, D. C., 16-17 March 1962.

Reviews history of research on effects of magnetic torques on rotating conductors and discusses the use of such torques for satellite attitude control.

158. WINDEKNECHT, T. G.
A SIMPLE SYSTEM FOR SUN ORIENTATION OF A SPINNING SATELLITE.
Institute of the Aerospace Sciences-American Rocket Society Paper No. 61-204-1898, presented at the IAS-ARS Joint National Meeting, Los Angeles, California 13 June 1961 . 26 pages.

159. WOLFE, R. R., J. M. CORGAN and P. B. TEETS
ENERGY REQUIREMENTS FOR SATELLITE STABILIZATION OF THE GRAVITATIONAL GRADIENT.
American Rocket Society Journal, 31:836-838, June 1961.

Satellite orientation about a gravitationally unstable reference is examined, and equations of motion are linearized and integrated, to determine energy requirements for an attitude control system.

160. WORMSER, E. M. and M. H. ARCH
INFRARED NAVIGATION SENSORS FOR SPACE VEHICLES.
American Rocket Society, Paper No. 1928-61,presented at the ARS Guidance, Control and Navigation Conference, Stanford, California . 7-9 August 1961 . 7 pages.

161. ZOJAC, E. E.
CAPTURE PROBLEM IN GRAVITATIONAL ATTITUDE CONTROL OF SATELLITES.
American Rocket Society, 31:1464-1466, October 1961.

If the satellite is initially oriented in a way that satisfies the first two conditions of a set of orientation conditions, it will be captured by the gravitational gradient subsequent motion will occur in the neighborhood of the desired orientations.

162. ZOECKLER, D. J.
MERCURY CAPSULE REACTION CONTROL PROPULSION SYSTEM.
Missiles and Space, October 1962, pages 22-24,56,58.

Describes a jet reaction attitude control which has 90% hydrogen peroxide as its propellant.

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